YO997-410

SMOOTHING CALIBRATION FILES TO IMPROVE REPRODUCTION OF DIGITIZED IMAGES

FIELD OF THE INVENTION

The present invention is directed to the field of digital
5 imaging and more specifically directed to reproduction of
digitized images.

BACKGROUND OF THE INVENTION

It is becoming more and more important to be able to
store vast amounts of digitized images in storage media.
10 The so stored image becomes available for display or
reproduction. Images are normally stored with separate
data representing a color plane for each color. Thus a
color image represented in red, green and blue (RGB), has
three color planes. A monochrome image has a single
15 color plane. The color plane data is used to reproduce
the color image. The faithfulness of the reproduction is
affected by several factors. One of these factors is the
usage of a white calibration profile. It is an essential
part of digital capture achieved through many scanners.
20 The white calibration profile forms the basis for
applying corrections to each measured RGB signal. There
are several reasons for the need for such a correction.
The reasons stem from the operating environment of the
scanner and the response of the scanner elements, the CCD

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pixels. First, it is practically impossible to achieve
perfectly uniform illumination of the object to be
imaged. There is typically some variation of the
intensity level of the incident illuminant light as a

5   function of the position on the imaging table, and also
as a function of time. Secondly, the response of the CCD
pixels may also vary with time, and the signal gain may
vary from one pixel to another. An attempt to overcome
these problems uses a technique to normalize the response

10   of each CCD pixel relative to a reference signal. The
reference signal is typically the reflection or emission
from a calibration surface at each pixel, and/or the
absence of a reflection or transmission passing through a
surface.

15   A calibration surface is used to measure a reference
signal which is employed for purposes such as
normalization and standardization of arbitrary signals.
The reference signal is also termed the calibration
profile. A typical embodiment of a calibration surface

20   reflecting light takes the form of a white diffuse
reflector such as chromalin, in which case the
calibration profile is also termed the white calibration
profile. Other surfaces may be employed in the scope and
spirit of this invention.

25   A prevalent method is to directly employ the scanned
image of a white reflecting and/or emitting surface to
create a white calibration profile, and the scanned image
of darkness to create a black calibration profile.
Darkness is also referred to herein as a dark image. All

30   subsequent scans are normalized with respect to these

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white and black profiles. However, it has been found
that several problems may interfere in the development of
valid calibration profiles. The white signal typically
contains high frequency variations, caused by variations

5   in the light source as well as the CCD response of each
pixel. Furthermore, the white calibration image may
contain regions of relatively low intensity around the
edges, especially if the size of the white reflecting
and/or emitting surface is inappropriate. Finally, power

10 supply variations may cause spikes in the white and or
black calibration profiles.

The techniques employed heretofore in developing a white
and/or black calibration profile do not overcome several
key obstacles. These obstacles are typically encountered

15 in the practical implementations to obtain valid
calibration data values. One obstacle is the variations
in the light source, and in the response of the CCD
pixels. These tend to induce variations in the white
calibration data. Another obstacle is the spikes in the

20 system power supply which may severely corrupt the white
calibration data. Also, blotches on the white
calibration surface as well as dust on the camera optics
generally cause errors during the calibration process.

It is noted that digitized images are employed for

25 forming digital libraries. These encompass digital
capture, storage, retrieval and rights management of a
large number of objects such as paintings and
manuscripts. The digital capture system ought to support
accurate color reproduction so that the digitized image

30 captures the original as faithfully as possible. These

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depend upon developing and using a valid white and/or black calibration signal.

Thus, a solution is sought which smooths the white and/or black calibration file to remove high frequency

5   variations, extends the white and/or black signal all the way to the boundaries, and removes the effects of power source spikes. It is also advantageous that the solution include the flagging of the presence of problems in the white and/or black calibration data, such as unacceptable

10   deviations. Without the flagging of these problems, a corrupt white and/or black calibration profile could be erroneously used, rendering all subsequent scans that are based on this calibration to be faulty.

SUMMARY OF THE INVENTION

15   In an embodiment the invention provides a system for obtaining at least one calibration profile for an image scanning apparatus, the system comprising: a light source; a white image having a surface illuminated by the light source; a detector to measure an intensity of light

20   reflected and/or emitted from the white image at a plurality of positions; a first memory to store a first plurality of light intensity values measured by the detector at each of the positions; and a smoothing module to smooth the plurality of light intensity values in the

25   first memory so as to form a white calibration profile.

In an embodiment of the invention the system further comprises a value corrector to correct a second plurality

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of light intensity values measured by the detector for
the light reflected; and/or emitted from an arbitrary
image at each of the positions using the white
calibration data; and/or the white image has uniform

5   reflectivity and/or emissivity across the surface; and/or
the smoothing module is useful to employ filtering;
and/or the smoothing module is useful to employ
extrapolation and decimation upon data of a subset of the
plurality of positions, and/or the detector is also

10   useful to measure an intensity of light from a dark image
at the plurality of positions, and the first memory is to
also store a plurality of black intensity values measured
by the detector at each of the positions to form a black
calibration profile, and/or the smoothing module is also

15   useful to smooth the plurality of black intensity values
in the first memory, and/or the smoothing module is
useful to employ extrapolation, filtering and decimation
upon data of a subset of the plurality of positions.

Another aspect of the invention is a system for scanning

20   images, comprising: means for providing light; means for
measuring at a number of positions the intensity of light
emitted from the means for providing light transmitted
through a transparent object (which includes air etc.) to
form a first raw profile; and means for smoothing the

25   first raw profile to form a white calibration profile.
In some embodiments the system further comprises means
for measuring the intensity of light from the light
transmitted through an opaque object at the number of
positions to form a second raw profile; and means for

30   smoothing the second raw profile to form a black
calibration profile; and/or means for measuring the

intensity of light from the light transmitted through a
semi-transparent object at the number of positions to
form a semi-transparent object profile; and means for
correcting the semi-transparent object profile using the

5   white calibration profile; and/or means for correcting
the semi-transparent object profile using the black
calibration profile.

Another aspect of the invention is a method for improving
an initial calibration profile having an initial profile

10   extent to form an improved calibration profile, the
initial profile formed for a scanner employing a linear
array CCD and having a direction of motion, the method
comprising: forming an extended profile extent in the
direction of motion using quadratic extrapolation;

15   applying multirate filtering to the extended profile to
form a filtered profile; and truncating the filtered
profile to bring it to the initial profile extent to form
the improved calibration profile.

In one embodiment of this aspect, the method further

20   comprises comparing the improved calibration profile to
the initial calibration profile to determine at least one
occurrence of a problem condition; and flagging said at
least one occurrence; and/or evaluating the flags of said
at least one occurrence to determine the usability of the

25   improved calibration profile, and/or the calibration
profile is a white calibration profile; and/or the step
of forming extends a subset of the initial calibration
profile by a factor of four.

Another aspect of the invention is an article of
manufacture comprising: a computer usable medium having
computer readable program code means embodied therein for
causing the development of a valid calibration profile

5   for a scanning system, the computer readable program code
means in said article of manufacture comprising computer
readable program code means for causing a computer to
effect: scanning an image to obtain the plurality of
calibration signals to an initial extent of the image;

10   extrapolating the calibration signals to form extended
range signals; applying multirate filtering to the
extended range signals to form a plurality of filtered
signals; and truncating the plurality of filtered signals
to the initial extent to form said at least one valid

15   profile.

In an embodiment the article of manufacture, the at-
least-one-valid profile includes both a white and a black
calibration profile, and/or further comprising computer
readable program code means for causing the computer to

20   effect scanning an arbitrary image to obtain a plurality
of arbitrary signals; and employing said at least one
calibration profile to correct the plurality of arbitrary
signals.

Another aspect of the invention is a program storage

25   device readable by machine, tangibly embodying a program
of instructions executable by the machine to perform
method steps for developing a valid calibration profile
for a scanning system, said method steps comprising:
scanning an image to obtain the plurality of calibration

30   signals to an initial extent of the image; extrapolating

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the calibration signals to form extended range signals;
applying multirate filtering to the extended range
signals to form a plurality of filtered signals; and
truncating the plurality of filtered signals to the
5   initial extent to form said at least one valid profile.
In an embodiment the program storage device readable by
machine, the at-least-one-valid profile includes both a
white and a black calibration profile.

Another aspect of the invention is a method for scanning
10   images, the method comprising: providing a source of
light; measuring at a number of positions on a
transparent object, the intensity of light emitted from
the source of light transmitted through the transparent
object and forming a first raw profile; and smoothing the
15   first raw profile to form a calibration profile. In some
embodiments the method further comprises: measuring the
intensity of light from the source of light transmitted
through an opaque object at the number of positions to
form a second raw profile; and smoothing the second raw
20   profile to form a black calibration profile; and/or
measuring the intensity of light from the source of light
transmitted through a semi-transparent object at the
number of positions to form a semi-transparent object
profile; and correcting the semi-transparent object
25   profile using the white calibration profile; and/or means
for correcting the semi-transparent object profile using
the black calibration profile.

BRIEF DESCRIPTION OF THE DRAWINGS

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These and other objects, features, and advantages of the present invention will become apparent upon further consideration of the following detailed description of the invention when read in conjunction with the drawing

5   figures, in which:

FIG. 1(a) shows a block diagram of a typical system embodiment for improving the white and/or black calibration of a scanner through the use of smoothing;

FIG. 1(b) shows a lighting setup with the light source
10 above the image that may be used for digital imaging;

FIG. 1(c) shows a lighting setup with the light source below the image that may be used for digital imaging;

FIG. 2 shows how the black and white signal values are used to arrive at the normalized signal values for an
15 embodiment of the present invention;

FIG. 3 illustrates an example of a filtering operation performed upon a CCD element in accordance with the present invention;

FIG. 4 shows an example of the steps to smooth a white
20 calibration profile, in accordance with the present invention;

Fig. 5(a) shows an example of a decimation step, in accordance with the present invention;

Fig. 5(b) shows an example of an interpolation step, in accordance with the present invention;

Figs. 6(a), 6(b) and 6(c) illustrate results of extrapolation through a quadratic followed by multirate

5   filtering, in accordance with the present invention;

DETAILED DESCRIPTION OF THE INVENTION

Figure 1(a) shows a block diagram of a typical system embodiment for improving the white and/or black calibration of a scanner through the use of smoothing.

10   It shows an image capture and distribution system 100. The system 100 includes a scanner 101 which captures image data 102 from a physical scene 103. The physical scene 103 is typically a painting, a photograph, a physical object and its surrounds, or a test chart.

15   Although the invention is not limited to any specific context, the scanner 101 sends original image data 102 to a digital computer 104. The computer 104 includes a working storage 106 that is typically embodied in the computer s random access (or other) memory, an image

20   storage system 108 that is often a conventional hard disk drive (or other non-volatile storage device), and an image archive 110 that can be a tape or disk storage (or other non-volatile storage device). The computer 104 also includes a number of modules which are usually

25   implemented in software. These include a front end image processor 112 that performs image processing such as scaling and enhancement of the image data provided by the scanner 101. It also includes white and/or black

calibration controller 114 operating in accordance with the principles of the present invention, and back-end image processing software 116 that performs other processing functions. These other processing functions

5   may include compression of the image and storing white and/or black calibration value data 117 for one or more scanners. The white and/or black calibration value data 117 may be used on other digitized images scanned by the scanner 101. Quite often, the unprocessed or front-end

10   digitized original image data 102 is sent to the image archive 110 for preservation in unaltered form.

An alternate embodiment has data of an original image in digitized form 102 and white and/or black calibration value data 117 already available without requiring a

15   scanner 101. The white and/or black calibration software 114 applies white and/or black calibration to the digitized image 102 in accordance with the principles of the present invention. The white and/or black calibration process can also be performed on a copy of an

20   image in the archive 110, or on other scanned and processed image data which has been loaded in whole or in part, into the computer s working storage 106. This may be done provided the other image's data were obtained using the same scanner at scanning conditions similar to

25   the scanning conditions used to obtain the white and/or black calibration value data. Similar conditions means that other images were optically focused using the same scanner and similar settings for such items as focal distance, lens aperture and colored filters.

The processed, white and/or black calibration and
compressed image data produced by the combination of
modules 112, 114, 116 may be sent from the working
storage 106 or image storage 108 to an image server 118
5   that is connected to a digital network 120. When
appropriate, the digital network is interconnected with a
Local Area Network (LAN), a Wide Area Network (WAN) such
as the Internet, or both. Other systems 122 connected to
the digital network 120 can request and receive images
10 stored on the image server 118 via the digital network
120. In some cases, the systems can then display the
received images on a display device 124 and/or print the
images on a graphics capable printer 126. Those skilled
in the art will recognize that there are many other
15 system configurations in which the present invention
could be employed.

Figure 1(b) shows a lighting setup that may be used for
digital imaging. It shows light sources 151 and 154 used
to illuminate an object 152. The light reflected (or
20 transmitted through) the object is captured by a light
sensitive device such as a CCD chip embedded in a digital
camera 153. Examples of suitable light sources are:
halogen lamps, tungsten lamps, and fluorescent lamps.

The setup of Figure 1(b) is for a reflective setup, where
25 light bounced off the object 152 is imaged onto a CCD
chip contained in a digital camera 153. In a
transmissive setup, light transmitted through the object
is imaged. In this case, the light sources 152 154 are
below the object as shown in Figure 1(c). This is also
30 sometimes referred to as an emissive setup.

In order to get an accurate measurement for the intensity values of color planes of a color image, for example the RGB (red, green, blue) planes, one needs to take into account the CCD signal in the presence of no light (black

5   signal) and maximum light (white signal). The black signal is obtained by placing a black filter in front of the CCD. The white calibration signal is obtained by placing a white diffuse reflector (such as chromalin) under the camera. Figure 2 shows how the black and white

10   signal values are used to arrive at the normalized signal values. For illustration, the red channel is considered. The output signal, R_{out} 208 is related to the input signal R_{in} 202, the black signal $R_{b\text{-}initial}$ 204, $R_{b\text{-}scan}$ 210, and the white calibration signal R_w 206 as follows:

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$$R_{out} = (R_{in} - R_{b\text{-}scan})/(R_w - R_{b\text{-}initial})$$

$R_{b\text{-}initial}$ is measured at the time of calibration. $R_{b\text{-}scan}$ is measured at the scan time of every image. Thus the measurement of white and/or black signal values is critical as it affects every pixel in the scanned image.

20   Ideally, one would expect the white and/or black signal to be a smooth function of image position, with fairly constant values. However experimentation has shown us that this is not true, for a variety of reasons:

        1.   The white reflecting surface that is being
25   imaged has blemishes or scratches.

        2.   The lens or filter may have specks of dirt
        or dust.

3. There are variations in the lamp intensity as a function of time.

4. The power to the lamps varies as a function of time, and may occasionally contain spikes.

5   5. The white surface does not cover all of the intended imaging area.

6. Light leakage into the lens when developing the black calibration profile.

7. Power supply spiking and variations.

10   8. When the scanner has multiple sensors, each sensor has a different characteristic.

Thus, it is necessary to smooth the white and/or black calibration signal in order to eliminate erroneous calibration signals owing to these defects, and/or to
15 identify the presence of any remaining spikes or other significant deviations. This will alert the scanner operator to take necessary corrective actions.

A significant aspect of the present invention lies in recognizing the problems with raw white and/or black
20 calibration signals, and positing that the white and/or black calibration signals be smoothed.

Several techniques were investigated to perform this smoothing operation. In one technique, the white and/or black calibration data may be smoothed by fitting the

calibration data to a parametric model. This could
employ either linear or non-linear least squares.
Alternate techniques implement smoothing using optimal
filtering.

5   When a parametric model is employed it often assumes a
form of the function, such as a polynomial for a typical
signal denoted by R(x,y). Let 'x' represent a pixel row
number, and 'y' represent a pixel column number, then
R(x,y) represents the light intensity value measured by
10   the CCD sensor at the pixel location given by 'x' and
'y'. Then:

$$R(x_0,y) = a_0 + a_1y + a_2y^2 + a_3y^3 + \ldots a_{N-1}y^{N-1}$$

where $R(x_0,y)$ is the light intensity value at $x=x_0$.
This equation is a polynomial of order 'N-1', and
15   contains 'N' coefficients to be estimated from the data.
This estimation can be carried out by the well known
procedure of least squares, where the square of the fit
error between the estimated polynomial and the actual
data is minimized. Other parametric forms can be
20   assumed, such as splines, etc.

The second technique involves using filtering operations,
performed upon the white and/or black calibration data.
In these operations the true signal is assumed to be
corrupted by noise, and the objective is to recover the
25   true signal from the corrupted signal. Typically the
noise contains broad spectral frequencies, whereas the
signal contains a limited band of frequencies, usually
low frequencies. Thus, by using a low-pass filter, one

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eliminates the high frequencies that are due to noise. The low frequencies that constitute the signal are retained.

For the purpose of describing the present invention, an
5   efficient implementation of low pass filtering is described. However, an interesting aspect of the present invention is that in a further embodiment both the above techniques may be combined to smooth the data. First a parametric fit is performed to fit the end points of the
10 data so as to extend the signal, and then the resulting extended signal is filtered.

An example embodiment of the present invention uses one of the two most popular imagers. These are the line-scan CCDs and the area CCDs. In the line-scan CCD, of which
15 the IBM TDI Pro/3000 scanner is an example, the CCD is a one-dimensional linear array which is translated across the imaging area. In the area CCD, the entire imaging area is captured with a single two dimensional CCD, with no need for translation.

20 In general, the choice of filtering technique depends upon the type of CCD being used. For linear array CCDs it suffices to apply one dimensional filtering in the direction of translation of the CCD. This is because one does not wish to smooth signal values across CCD pixels,
25 since the CCD pixels may have variable gain. For area CCDs, one may choose to fit a low order polynomial surface patch over the entire two dimensional array, and flag significant deviations between the fitted surface and the actual surface.

Figure 3 illustrates an example of a filtering operation
performed upon a CCD element 300. It also shows the
coordinate system that is used herein. Let 'N' be the
number of pixels in the 'X' direction, and 'M' be the

5   number of pixels in the 'Y' direction. In other words,
the CCD element effectively produces an image containing
'M' rows and 'N' columns. A typical signal will be
denoted by R(x,y), where 'x' represents a row number,
ranging from 1 to 'M' and 'y' represents a column number,

10   ranging from 1 to N, and R represents the light intensity
value measured by the CCD sensor at the location given by
'x' 306 and 'y' 308. A typical signal R(x,y) 310 is
shown in the figure for the CCD pixel at $x = x_0$ 312. In
this example the signal is smoothed in the direction of

15   motion, i.e., we hold 'x' fixed and smooth

$$R(y) \text{ at } x = x_o$$

for all 'x_o' ranging from 1 through 'N'.

This type of smoothing is a very important and surprising
aspect of the invention. After all, these data are

20   supposed to reflect the true state of the various CCD
sensor pixels, where different CCD sensor pixels may have
different gains. This causes the output of two CCD
pixels, measured in terms of current or voltage, to be
different for the same input. The output has a specified

25   amount of illumination measured in units of power, such
as watts. In fact, in most cases if the calibration data
is smoothed along the direction of the CCD pixels (the
'X' direction, as per Figure 3), one usually gets poor
results as the smoothing is performed across pixels with

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different gains. This usually defeats the entire purpose
of calibration.

Given this consideration, it is not clear whether
smoothing the calibration data in the perpendicular
5   direction, i.e. the 'Y' direction, will give rise to
better results. A series of experiments were performed
to test smoothing in the 'Y' direction. The results were
not expected until the experiment was completed. The
results showed that smoothing in the Y direction is very
10   advantageous. In most cases it was found that smoothing
the white calibration data in the Y direction resulted in
the elimination of off-color streaks across the image
that occurred due to power surges. Thus, although
improper use of smoothing can lead to totally erroneous
15   results, judicious use of smoothing operations however
does lead to significant improvements in the white and/or
black calibration.

Since the essential filtering techniques are the same,
for most CCDs, an implementation example is described for
20   the case of linear array CCDs. The filtering consists of
the following steps, summarized in a flowchart in Fig.
4.

        1. obtaining a white and/or black calibration
        signal, $R(x,y)$, containing a plurality of image
25   intensity measurements by scanning a white
        and/or black object 410 (The white and/or black
        object may be a white and/or black paper such
        as 'Chromalin', manufactured by DuPont);

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2. extrapolating the signal R(x,y) in either
direction along the 'Y' axis, i.e. the
direction of motion of the sensor array, using
an appropriate extrapolation method, such as

5   quadratic extrapolation 420;

(Extrapolation refers to the
estimation of signal values outside a
given interval based on signal values
within the interval)

10   3. applying multirate filtering to the
extended signal 430;

4. truncating the result to the extent of the
original signal 440;

5. interpreting the truncated signal 440 as

15   the smoothed white and/or black calibration
signal 450; and

6. comparing the resulting signal to the
original signal so as to flag the occurrence of
problem conditions.

20 In order to perform signal extrapolation almost any
filtering operation can be applied to the original signal
'R(x,y)' without modification. However, one of the
problems with some filtering technique is the choice of
an appropriate treatment of the end signal values. This

25 occurs in the vicinity of y = 1 and y = M, where 'y'
denotes the row number). Multirate filtering has a

tendency to flatten the signal at either end. In order
to avoid this, in an example embodiment of the present
invention, the original signal is extrapolated at both
ends. This may be performed as follows. A fraction of

5   the signal, (say one quarter), at each end is used to
estimate a polynomial fit (say a quadratic), and this is
used to extrapolate the signal (say to $y = -E + 1$, and $y = M + E$). Here 'E' denotes the number of points over
which the signal is extrapolated, and 'R_E' denotes the

10   extended signal.

In an example embodiment, the signal is extrapolated
outward at each end using one quarter of the signal
values at the corresponding end with a quadratic fit.
The number of points 'E' over which the signal is

15   extrapolated is ten percent of the length of the original
signal. In the example embodiment 'R_E' is filtered using
a multirate filtering technique described in, F. Mintzer
and B. Liu, "Aliasing Error in the Design of Multirate
Filters," ASSP, no. 1, pp 76-88, 1978, which is

20   incorporated herein by reference in its entirety. This
is a digital signal processing technique (as opposed to
optical filtering), which can be used to implement a low
pass filter. Multirate filtering is briefly summarized
in the two step shown in Figures 5(a) and 5(b). It

25   starts with a decimation step in which the sampling rate
of the signal is decreased by an integer fraction, and is
followed by an interpolation step where the number of
signal samples is increased by an integral amount.
Figure 5(a) shows the decimation step, where the original

30   signal 'R' 502 is down-sampled through the successive
application of a filter 'F' 504 displaced by an amount

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'd' 506 for each application. That is, the filter
coefficients 'F' are multiplied with the input signal 'R'
to obtain the resulting decimated signal 'S", given by:

$$S = {}_{i=1}\Sigma^{i=k} R(i) \ F(i)$$

5   where 'k' is the length of the filter. The filter 'F' is
then displaced by a distance 'd', and the corresponding
signal values are multiplied by the filter coefficients
as indicated in the figure. The result is a decimated
signal 'S' 508. In the figure, we show the case where
10   d=3 and k=5. Note that we can successively apply
multiple stages of decimation. That is, the operation
can be applied on 'S' to result in a further decimated
signal.

Figure 5(b) shows the interpolation step, where the
15   signal 'S' 522 is interpolated through the use of an
interpolation filter, 'F' 524. For the purpose of
illustration, the signal 'S' 522 has been interpolated to
increase the number of samples by a factor of 4. The
figure shows the interpolation of values between 'S(2)'
20   and 'S(3)' through the application of filter coefficients
on the signal values 'S(1)' through 'S(4)'. Note that
successive stages of interpolation can be consecutively
applied. This example uses the interpolation method
described in G. Goertzel, et al, "The design of
25   Interpolation Filters and Their Application to Image
Scaling and Rotation," herein given in Appendix A, and
incorporated herein by reference in its entirety.

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In the example embodiment, 'k=5', i.e. the filter 'F' consists of five points, whose values are [7/96, 24/96, 34/96, 24/96, 7/96]. These values are taken from "Digital Filters," R. W. Hamming, Prentice Hall, second

5 edition, 1983. The values for the five points are interpreted as performing a least squares filtering operation. The distance 'd' is set to be 5 pixels, so there is no overlap between successive applications of 'F'. Thus the number of samples is reduced by a factor

10 of five at each stage of decimation. In the example, two successive stages of decimation are applied.

This is followed by two stages of interpolation, where at each stage the number of samples is increased five fold. This example uses the interpolation method described in

15 G. Goertzel et al., given in Appendix A. For the sake of illustration, the coefficients used are shown in the example embodiment. It will be obvious to those skilled in the art that other interpolation techniques such as spline interpolation could just as well be used. In this

20 case there are five sets of four coefficients each, and the argument for each coefficient refers to the location of the point to be interpolated in the unit interval. These filter coefficients are used to weight the contributions of the signal values just prior to

25 interpolation, indicated by S(1) through S(5) in Figure 5(b). The first set of coefficients is interpreted as follows. F(0.2) gives the multiplication factor for the signal at position 0.2, units away (to the left) with weight 0.912883. The signal that is 1.2 away (to the

30 left) is multiplied with weight -0.0609059. The signal that is -0.8 units away (i.e. 0.8 units to the right)

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with weight 0.156397, and the signal that is -1.8 units away with weight -0.00837421. The sum of these weighted products is the desired interpolated signal value.

$F(1.2) = -0.0609059$

5    $F(0.2) = 0.912883$

$F(-0.8) = 0.156397$

$F(-1.8) = -0.00837421$

$F(1.4) = -0.0580303$

$F(0.4) = 0.685906$

10    $F(-0.6) = 0.403522$

$F(-1.6) = -0.0313974$

$F(1.6) = -0.0313974$

$F(0.6) = 0.403522$

$F(-0.4) = 0.685906$

15    $F(-1.4) = -0.0580303$

$F(1.8) = -0.00837421$

$F(0.8) = 0.156397$

$F(-0.2) = 0.912883$

$F(-1.2) = -0.0609059$

20    $F(1) = 0 \quad F(0) = 1$

$F(-1) = 0$

$F(-2) = 0$

Two stages of interpolation are used with the above set of coefficients in the example embodiment.

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The choice of an appropriate filtering technique is very important. If the size of the filter applied is too small, it causes a tendency to follow the high frequency variations in the signal. This may make it unable to

5   detect the presence of deviations such as power spikes. The result is truncated to the extent of the original signal, as there is no need for the extrapolated values at either end.

Many variations are possible, such as fitting a single

10   quadratic or cubic to the entire signal and/or smoothing with a Gaussian kernel. The technique presented in the example embodiment is both efficient and robust.

After performing all the operations shown in Figure 4, the processed signal is compared to the original signal

15   to flag problem conditions. For instance, one can employ a tolerance band around the final signal. In one embodiment the tolerance band is set at ±1%. If an input signal pixel lies outside this tolerance band, it is marked as an erroneous pixel. The tolerance band is

20   generally selected to be such as to provide a conservative judgment of the quality of the white calibration signal. If the white and/or black calibration signal lies within this tolerance band, one can generally be certain of the satisfactory quality of

25   the calibration data.

In one embodiment, the total number of erroneous pixels is tallied, and reported as a measure of the quality of the white and/or black calibration process. For instance, if there is a sufficiently large number of

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erroneous pixels, (say greater than 1% of the total
number of pixels), an error condition on the whole white
and/or black calibration process is reported. When an
error condition is reported suitable action is undertaken
5   to improve the imaging equipment used. This may include
replacing the light bulbs, checking the power supply,
and/or cleaning the optics.

In an actual implementation of the method described,
implemented in a C-program, superior performance resulted
10   when compared to unfiltered white calibration files. The
results of filtering of a few typical white signals are
shown in Figures 6(a), 6(b) and 6(c).

Figure 6(a) illustrates the result of extrapolation
through a quadratic followed by multirate filtering. The
15   curve with high frequency variations 602 is the original
signal, and the smooth curve 604 depicts the result of
filtering.

Figure 6(b) illustrates another result of extrapolation
through a quadratic followed by multirate filtering. The
20   curve with high frequency variations 612 is the original
signal, and the smooth curve 614 depicts the result of
filtering

Figure 6(c) illustrates still another result of
extrapolation through a quadratic followed by multirate
25   filtering. The curve with high frequency variations is
the original signal, and the smooth curve depicts the
result of filtering.

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There are many potential uses for the present invention.
It may be used with any CCD image that performs a white
and/or black calibration. The filtering operations
improve the final image. This is because the final pixel

5   value of every image pixel is a function of the white
and/or black calibration signal. Thus any improvement in
the white and/or black calibration signal improves the
appearance of the final image.

Appropriate use of the present invention reduces or

10   eliminates the problems associated with power supply
spikes upon the white and/or black calibration signals.
If power spikes are not filtered, scanned images may have
a stripe through them representing the power spike.

Problems due to blotches on the white surface, and dust

15   on the camera optics can are reduced or eliminated from
effecting the final image quality. The invention also
enables flagging information regarding the presence of
problems with the white and/or black calibration data.
This information can be used by scanner operators to take

20   corrective action. The methods of this invention were
used to enhance images scanned using the IBM TDI/Pro 3000
scanner.

It is noted that this invention may be used for many
applications. Although the description is made for

25   particular arrangements, the intent and concept of the
invention is suitable and applicable to other
arrangements and applications. It will be clear to those
skilled in the art that other modifications to the

disclosed embodiments can be effected without departing from the spirit and scope of the invention.